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September 12, 2000

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FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF THE SECRETARY

HAND DELIVERED

Magalie R. Salas, Esq.

Secretary

Federal Communications Commission

445 12<sup>th</sup> Street, SW, Room TW-B204

Washington, D.C. 20554

Re: Revision of Part 15 of the Commission's Rules  
ET Docket 98-153

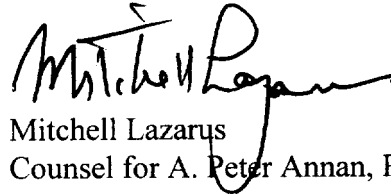
Dear Ms. Salas:

Enclosed are the original and nine copies of the Comments of A. Peter Annan for filing in the above-referenced docket.

Kindly date stamp and return the enclosed extra copy of the Comments.

If there are any questions about this filing, please call me at the number above.

Respectfully submitted,

  
Mitchell Lazarus  
Counsel for A. Peter Annan, Ph.D., P.Eng

ML:deb

Enclosures

cc: Service List  
A. Peter Annan

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Before the  
Federal Communications Commission  
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FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF THE SECRETARY

In the Matter of )  
 )  
Revision of Part 15 of the Commission's Rules ) ET Docket 98-153  
Regarding Ultra-Wideband Transmission )  
Systems )

**Comments of A. Peter Annan**

Pursuant to Section 1.415 of the Commission's Rules, A. Peter Annan, Ph.D., P.Eng., hereby files these Comments in the above-captioned proceeding.<sup>1</sup> Dr. Annan is an expert in ground penetrating radar (GPR) systems. The following comments specifically address ground coupled impulse or baseband GPR devices. Dr. Annan takes no position on other ultra-wideband applications.

**A. GPRs Are Properly Classed as Unintentional Radiators.**

The Notice proposes to regulate GPRs as intentional radiators. The facts, however, show that GPRs are properly treated as unintentional radiators.

The field generated by an intentional radiator falls off as  $1/r^2$ , where  $r$  is distance from the source, so that nonzero energy extends to unlimited distance. GPR signals, in contrast, are coupled into a ground medium which always has some loss. The energy follows  $e^{-2\alpha r}/r^2$ , so that no signal ever reaches indefinitely large distances. Moreover, there is no intentional radiation into space. Although some energy may leak above the material being examined, any such signals are undesired. These emissions are entirely spurious. Indeed, because they degrade the performance of a GPR system, manufacturers strive to minimize them.

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<sup>1</sup> Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET Docket 98-153, Notice of Proposed Rule Making, FCC 00-163 (released May 11, 2000) (Notice).

The Commission defines an intentional radiator as a “device that intentionally generates and emits radio frequency energy by radiation or induction.”<sup>2</sup> Although a GPR intentionally generates RF energy, it does not intentionally emit, and so does not qualify as an intentional radiator. An unintentional radiator, in contrast, is a “device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.”<sup>3</sup> This language better describes the operation of a GPR.

For the sake of consistency with its own definitions, the Commission should classify GPRs as unintentional radiators and subject them to the verification procedure. Because the interference potential from GPRs is so small, as explained below, there is no justification for imposing on manufacturers the burden of certifying these devices as intentional radiators.

**B. GPRs Present an Insignificant Risk of Interference.**

The practical risk of interference from GPRs is negligible.<sup>4</sup> There are several reasons:

- Nearly all of the emitted energy is directed into the ground, where it dissipates quickly in soil and rock. To maximize performance, every effort is made to keep the small fraction that might otherwise escape as low as possible by tight ground coupling and shielding.
- Unlike many other RF-emitting devices that function more or less continuously, GPRs operate only for very brief intervals, which are separated by long inactive periods. Even if the emitted energy were significant, the low duty cycle would greatly reduce the probability of actual harmful interference.
- Relatively few of these units will ever be deployed. A major urban center might eventually have tens or even hundreds of GPR systems available. But even then, the sporadic nature of their operation makes it unlikely that more than a

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<sup>2</sup> 47 C.F.R. Sec. 15.3(o).

<sup>3</sup> 47 C.F.R. Sec. 15.3(z).

<sup>4</sup> The Commission agrees. *See* Notice at para. 25.

few will ever be in use at the same time. Proliferation will be even lower outside the major urban areas.

The Commission's Rules should take into account that GPRs present less practical threat of interference than almost any other RF-emitting technology, including most other ultra-wideband implementations. Close regulation of these devices is simply unnecessary.

**C. The Proposal for an Automatic Switch is Impractical and Unwise.**

The Commission proposes to require "a switch or other mechanism to ensure that operation occurs only when it is activated by an operator and the unit is aimed directly down at the ground."<sup>5</sup> Although GPRs in fact may be operated in a downward orientation more often than otherwise, the Commission's suggestion nonetheless overlooks many other uses -- against steep slopes, into the sides of cliffs, on retaining walls backed by soil, in underground pipes and culverts, on tunnel roofs, on basement walls, etc. In practice the "ground" can be in any direction, even overhead. To require that a GPR be incapable of operating except when aimed downward would eliminate many of its most valuable applications. If the Commission does impose such a requirement nonetheless, it must allow manufacturers to add an override switch.

A requirement for a press-to-operate switch, on the other hand, is practical and acceptable. All GPR systems should have this feature, which will help to keep duty cycles low.

**D. Technical Rules for GPRs Need Special Consideration.**

GPRs are sufficiently different from other ultra-wide band devices, both in technical characteristics and in mode of use, that their technical rules need separate treatment in certain respects.

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<sup>5</sup> Notice at para. 25.

***Spectral lines.*** Ultra-wideband devices using a steady pulse repetition frequency (PRF) tend to produce emissions at fixed, evenly-spaced “lines” in the spectrum. The Commission proposes that these devices might be able to avoid interference into GPS by choosing a PRF whose spectral lines straddle the GPS frequencies.<sup>6</sup> Unfortunately this is not a practical solution for some GPRs. Spectral lines appear at intervals equal to the PRF. A typical GPR system must await the return of echoes before transmitting the next pulse, and so must operate at a relatively low PRF, in the range 1-100 kHz. The low PRF makes it impossible to space the spectral lines far enough apart to accommodate the GPS signals.

On the other hand, GPR emissions are so low -- due to attenuation by soil and rock, low duty cycles, and sparse deployment -- that even on-frequency spectral lines from GPRs present negligible threat to GPS.

Because GPR surveyors often use GPS technology for spatial positioning of the GPR measurement, the GPR industry community has a strong incentive to avoid any impact on GPS. The only GPR units that emit energy in the GPS band are those whose center frequencies lie in the 1-2 GHz range, and these generally produce emissions well below those specified in Section 15.209. In the proposal outlined below, all GPRs would be required to keep their emissions levels well under Section 15.209 levels across the GPS bands.

***Average emissions.*** As explained in the Appendix, different GPR models have center frequencies over the range 0.01-2 GHz, with the occupied bandwidth typically equal to the center frequency. Over most of this range, the Commission proposes to allow higher average emissions at higher center frequencies. GPRs, however, typically need more power at lower

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<sup>6</sup> Notice at para. 36.

frequencies. The proposed limits would be unworkable at center frequencies below about 250 MHz.

For reasons detailed in the Appendix, the following average emissions limits are both practical for GPR operations and safe for other users of the spectrum:

- center frequency below 50 MHz: average limit of 500 mW;
- center frequency above 250 MHz: average limit of 20 mW;
- center frequency between 50 and 250 MHz: average limit tapering linearly (on a logarithmic frequency scale) from 500 to 20 mW.

For a graphical representation, see Figure 5 in the Appendix.

The lower frequency GPRs, whose limits would exceed Section 15.209, are often characterized as geological mapping systems. Their main use is mapping geologic structure to depths of tens of meters below the surface. These systems primarily see use in rural and remote areas in mining applications, glacier sounding, major dam and road construction, etc. -- typically well away from population centers. These are important applications, and the Commission should find a way to accommodate them. Again, the vast majority of the energy produced is transferred into soil and rock, where it is converted into heat and poses no interference concern.

The proposed higher emissions below about 250 MHz are offset by lower emissions elsewhere, and result in significant added protection to GPS and other services near and above 2 GHz.

***Peak-to-average ratios.*** The Commission notes that victim receivers whose bandwidth exceeds the PRF may be sensitive to the peak value of the ultra-wideband signal, rather than the average value.<sup>7</sup> The Commission proposes to restrict peak-to-average ratios to 20 dB over any 50 MHz bandwidth, with overall limits increasing with occupied bandwidth up to 60 dB.<sup>8</sup>

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<sup>7</sup> Notice at para. 35.

This scheme might be suitable for some types of ultra-wideband equipment, but it is inappropriate for GPRs. (See the Appendix for a brief technical discussion of GPR operation.) In particular, peak-to-average ratio is poor measure of interference potential from GPRs. Interference potential can be independent of peak-to-average ratio, or even correlate negatively with it. As noted above, a typical GPR waits a minimum interval between pulses to allow echoes to return. Suppose the interval between pulses doubles, holding other variables constant. The peak value is unchanged. But the average energy emitted drops by half, and so the peak-to-average value increases by a factor of two -- yet the interference potential decreases, if it changes at all.

GPR systems with low repetition rates can easily show peak-to-average ratios up to 100 dB or more. For example, it would not be unusual to have a pulse duration of 1-2 nanosec, with a PRF of 10 kHz. This yields a peak-to-average ratio of on the order of 100 dB, although the potential for interference remains extremely small. Accordingly, GPRs should be permitted a peak-to-average ratio of 100 dB regardless of bandwidth.

***Underground operation.*** GPRs used in underground mines, drill holes, tunnels, pipes, etc. pose no conceivable threat of interference regardless of their emission levels, because the energy they produce can never reach a victim receiver in the outside world. The Commission should provide an exception that allows GPRs to operate underground without regard to the technical limits applicable to surface operation.

***Conducted emissions.*** Virtually all GPR systems operate from battery power. In the rare circumstances where a DC power supply may be used to drive the GPR unit, there is

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<sup>8</sup> Notice at para. 43.

extensive isolation between the GPR instrumentation and the AC line. There is no reason to increase the conducted limits above the standard allowed for digital devices in Part 15.<sup>9</sup>

***Measurement procedures.*** The Commission's emphasis on simple and straightforward measurement techniques is well placed.<sup>10</sup> Different types of ultra-wideband devices, however, may call for different methods of measurement. The Commission should keep in mind the importance of rules that permit inexpensive and practical measurement, even if those involve a degree of estimation and approximation.

GPR systems that operate at relatively low frequencies (with center frequencies and bandwidths below about 250 MHz) have long wavelengths and large antennas. Accurate reproduction of real-world conditions could require test cells up to tens of meters in size. For these units, the Commission should permit measurement of transmitter output into a resistive load impedance equivalent to the antenna it normally drives. At these frequencies, the bulky size limits practical antennas to electric or magnetic dipoles. A mathematical model for the antennas on a variety of soil conditions can be used to indicate the maximum level of emission that could be transferred into the air from an antenna placed on the ground.

GPRs with center frequencies above about 250 MHz are more amenable to testing in existing facilities. All GPR systems use transducers that are fabricated to work in close proximity to the ground, although spurious emissions into the air can occur if the transducer is not well coupled to the ground. The measurement procedure thus must account for imperfect coupling, which will strongly effect the measured emissions. Yet, to prescribe a test cell

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<sup>9</sup> See Notice at para. 45.

<sup>10</sup> Notice at para. 49.

procedure that emulates representative operating conditions would be complex and unlikely to yield reproducible results. A more practical approach would take measurements with minimum coupling -- *i.e.*, with the device under test suspended in the air -- and then subtract a compensation value to represent actual behavior in the field. The appropriate compensation factor, probably about 20-40 dB, can be established from simple theoretical models and tested by one-time field measurements.

Quasi-peak measurements. Standard quasi-peak emission measurement techniques provide good information on the spectral output of current GPR systems, and are available at many test houses.

Antennas. The Commission correctly noted that the antenna used for peak measurements will have a major effect on the peak observed.<sup>11</sup> Cavity backed spiral antennas should not be used for this purpose because their response is polarization-dependent on frequency. Better are horn antennas or calibrated dipole antennas that are short compared to the shortest wavelength in the signal, and are matched to their measurement apparatus. The short dipole essentially provides the time derivative of the incident signal in the vector direction of the alignment of the dipole, which provides a stable measurement of incident field.

Frequency range. For GPRs, the center frequency can be determined with a quasi-peak spectral analysis scan over the full range of the device. Obviously there are limitations if the device operates outside of the antenna transducer range of the particular apparatus, but this is not normally a problem with GPRs. The alternative is to measure the frequency content of the electronic pulse generator. These data must be combined with the pass-band of the antenna system to derive the bandwidth or center frequency of the system. This is ordinarily a straightforward measurement for GPRs.

## CONCLUSION

GPRs differ in important respects from other ultra-wideband devices, and the Commission's Rules should reflect these differences.

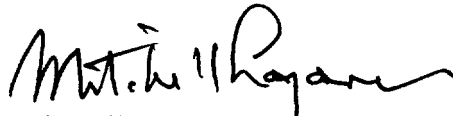
Because GPRs do not intentionally radiate RF into the ether and present an extremely low threat of interference, they should be regulated as unintentional radiators, and made subject to verification rather than certification.

The Commission's proposal to require a switch that permits operation only when the device is aimed downward would eliminate some of the most valuable uses of GPRs.

Finally, the technical rules for GPRs should accommodate their special characteristics, including higher permitted powers at low center frequencies and peak-to-average ratios independent of bandwidth.

The Commission should resolve this proceeding and promulgate rules expeditiously, so the public can benefit as soon as possible from GPRs and other ultra-wideband technologies.

Respectfully submitted,



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September 12, 2000

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<sup>11</sup> Notice at para. 54.

## **APPENDIX**

### **GPR Emissions and Regulatory Considerations**

**By A. Peter Annan, Ph.D., P.Eng.**

#### **1. Fields & Radiator Power Based on FCC Regulations**

The current UWB NPRM proposes that ultra-wideband GPR devices follow the existing emission levels as defined in Part 15.209. The following Table provides these levels and gives the units of measurement in a number of forms.

**Table 1 FCC Part 15.209 limits**

<b>FREQUENCY (MHz)</b>	<b>Electric Field (<math>\mu\text{V}/\text{m}/\sqrt{\text{BW}}</math>)</b>	<b>Distance (m)</b>	<b>Power (<math>\text{nW}/\text{BW}</math>)</b>	<b>Bandwidth (BW)</b>	<b>Electric Field (<math>\text{dB}\mu\text{V}/\text{m}/\sqrt{\text{BW}}</math>)</b>
1.7 - 30	30	30	27	120 kHz	29.5
30 – 88	100	3	3	120 kHz	40
88 – 216	150	3	6.75	120 kHz	43.5
216 – 960	200	3	12	120 kHz	46
960 +	500	3	75	1000 kHz	54

The levels defined in Table 1 are based on power spectral densities definitions for quasi-peak or peak measurements following standard procedures. For frequencies below 1000 MHz, measurements are normally made using quasi-peak measurements (CISPR 16-1) where a 120 kHz bandwidth (BW) is specified. Above 1000 MHz, a peak detection approach is normally used and a bandwidth (BW) of 1 MHz (1000kHz) is specified.

#### **2. Total GPR Power – NPRM Proposed Limits**

Normally GPR systems operate with a bandwidth to center frequency ratio of 1. The goal is always to achieve the maximum bandwidth at the lowest possible range of frequency. The normal GPR bandwidth is defined as the -6 dB point, while the NPRM uses the -10 dB point. For the current discussions, we will follow the normal procedure in the GPR community of specifying bandwidth at the -6 dB points, which yields a slightly lower value for the bandwidth than the -10dB definition.

Based on this assumption, and the FCC Part 15.209 limits of field strength given in Table 1, the proposed total radiated power allowable for a given GPR center frequency (and bandwidth) would be as defined in Table 2.

**Table 2 Total radiated power as defined by Part 15.209 for typical GPR center frequencies**

<b>GPR Center Frequency or Bandwidth (f<sub>c</sub>) (MHz)</b>	<b>GPR BW / Part 15.209 BW</b>	<b>15.209 Power / Unit Bandwidth (nW)</b>	<b>GPR Total Emitted Power based on 15.209 (mW)</b>
12.5	100	27	2.7
25	200	27(?)	5.4
50	400	3	1.2
100	800	6.75	5.4
200	1600	9	14
225	1875	9	17
250	2083	9	19
450	3750	12	45
500	4166	12	50
900	4583, 350	12,75	55+26=81
1000	4166, 500	12,75	50+38=88
1200	3333, 800	12,75	40+60=100
1500	2083, 1250	12,75	25+94=119
2000	2000	75	150

Table 2 is based on typical frequencies of actual GPR systems. Multiple entries in the lower lines of the table reflect the fact that the system bandwidth overlaps the boundary between 120 kHz and 1 MHz measurement bandwidths. To obtain total power, the system bandwidth is divided by the Part 15.209 measurement bandwidth, and multiplied by the power at the center frequency shown in Table 1. This calculation tends to err on the low side.

Tables 2 permits translation back and forth between the terms “average” power as used by most GPR vendors and the part 15.209 field strengths.

Table 2 shows that using the standard power spectral density definition for acceptable field strengths yields higher allowable “average” power as center frequency and bandwidth increase.

### 3. Fundamentals of Pulsed UWB Systems

In time domain UWB systems, there is a continuous sequence (albeit interruptible) of impulses spaced at some time apart. This is shown in Figure 1. The basic parameters of this signal are the peak signal level (or signal voltage) V, the pulse duration T, and the time interval between pulses W. More complex wavelets could be used but the essence of the problem is just as well

illustrated using a rectangular pulse. The information is summarized for the various parameters below Figure 1.

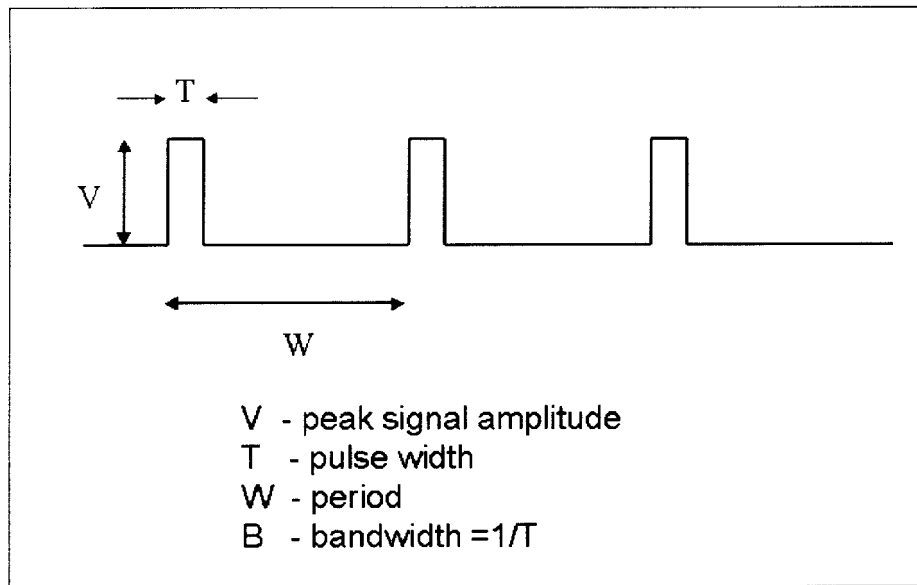


Figure 2 Simplified pulse sequence used to illustrate peak and average power concepts in the case of impulsive – time domain GPRs.

For reference purposes, the peak power is defined as

$$P_{\text{peak}} = \frac{V^2}{Z}$$

where Z is the impedance of the load . The average power is

$$P_{\text{ave}} = \frac{V^2}{Z} \cdot \frac{T}{W} = \frac{V^2}{Z} \cdot \frac{f_R}{B}$$

The repetition frequency is

$$f_R = \frac{1}{W}$$

and the peak to average ratio is

$$\frac{P_{\text{peak}}}{P_{\text{ave}}} = \frac{W}{T} = \frac{B}{f_R}$$

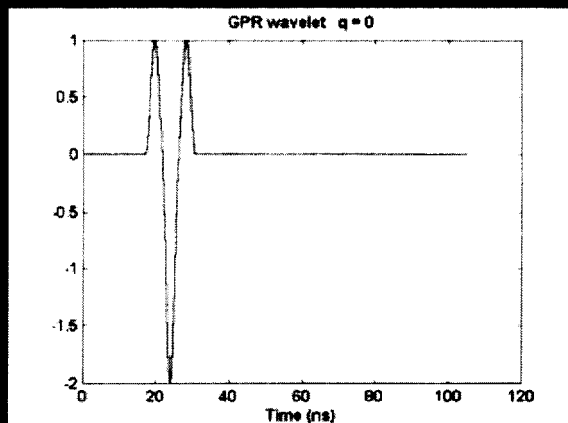
The key result of this simple analysis is as follows:

- a) for a fixed field strength or voltage, the average power decreases as system bandwidth increases, all else being equal;
- b) the peak-to-average ratio increases linearly with bandwidth, all other parameters being held constant;
- c) the average power increases linearly with the repetition frequency of the signal, all else being held constant.

Comparing these results to those in Table 2, we see a serious mismatch between the proposed rules and industry requirements. The proposed rules would allow increased power for increased bandwidth, while GPRs actually need increased power at *lower* bandwidths. A suggested resolution to this problem appears below.

#### **4. GPR Practicalities**

- 4.1 In practice, impulsive UWB GPR systems drive an impulsive voltage onto a well-controlled antenna designed to emit the impulsive signal or a carefully modified version with fidelity. The emitted signal has a spectral content dictated by the product of the transfer functions of the antenna and the driving impulse. Electric dipole antennas (or slight variations thereof) are employed. The spectral content of the impulse is band limited at the high frequencies to assure that the physical size of the dipole is less than or equal to  $1/2$  wavelength at all frequencies in the pass band of the system. The emitted impulse and the corresponding spectra typical of such systems are depicted in Fig 2.



## Short dipole impulse response

← 100 MHz wavelet

100 MHz wavelet  
spectrum

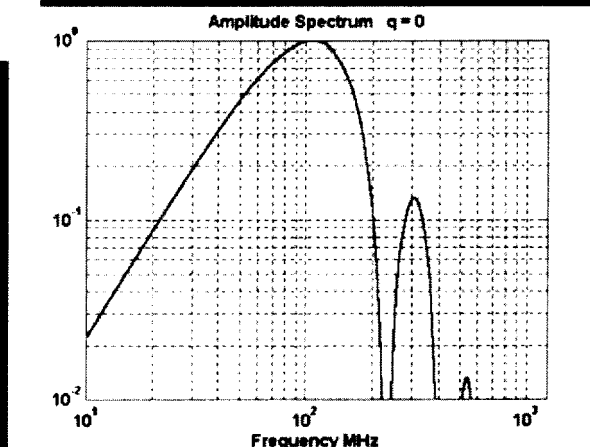


Figure 2 Typical GPR emitted pulse and normalized amplitude spectrum. A 100 MHz center frequency that would be emitted by 100 MHz impulse GPR system is shown. Changing frequency just stretches or compresses the time or frequency axis but the wavelet and spectra shapes remain the same.

4.2 In general the rate at which the voltage can be switched is inversely proportional to the bandwidth. The faster that one wishes to switch the voltage, the lower the peak voltage will be. In other words, the applied voltage varies inversely with the bandwidth of the signal (i.e., is proportional to the rise time). The essential concepts are shown using a triangular pulse as depicted in Fig 3.

This is a fundamental limitation of electronic devices and the value for  $C$  readily available is on the order of  $10^9$  V/s. Research and development continually increase the value of  $C$  and specialty research groups can justifiably claim that much higher values are feasible. Since 1985, GPR manufacturers have not taken advantage of the full higher values of  $C$  because of the concerns about emission levels posed in various regulatory regimes around the world.

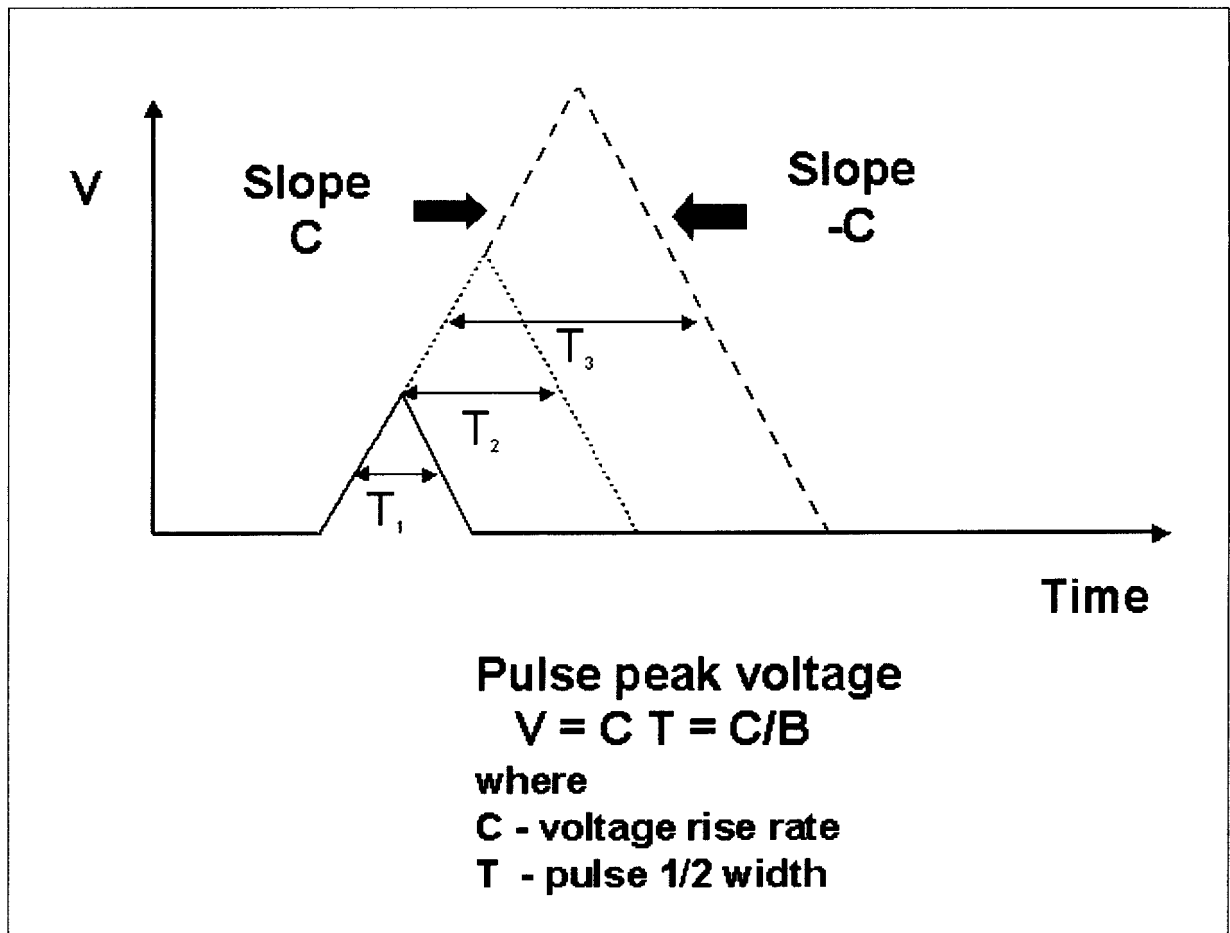


Figure 3

4.3. The signal repetition rate and the bandwidth of the signal are constrained for GPR systems. In general, a pulse is emitted and echoes are recorded over a subsequent time period. Typically the bandwidth to pulse repetition frequency ratio is on the order of 100:1 to 10,000:1. One can use 1,000:1 as a typical current value for this factor.

This ratio is just a measure of the spatial duration of the impulse (which reflects the resolution length of the system) to the range or the depth of penetration of the GPR signal into the medium under examination. It should always be remembered that GPR systems have to adapt to a wide range of applications and environments.

4.4. Using these constraints, one finds that the peak power is expressed as

$$P_{\text{peak}} = \frac{C^2}{Z \cdot B^2}$$

Assuming a bandwidth to repetition rate ratio of 1,000, the average power would be expressed as

$$P_{ave} = \frac{C^2}{Z \cdot B^2} \cdot \frac{f_R}{B} \approx \frac{C^2}{Z \cdot B^2} \cdot \frac{1}{1000}$$

and the peak to average ratio would be

$$\frac{P_{peak}}{P_{ave}} = \frac{W}{T} = \frac{B}{f_R} \approx \frac{1000}{1}$$

4.5. The typical GPR power transfer efficiency to the antenna is on the order of 1%. In other words, the antenna loss is on the order of -20 dB, since every effort is made to dampen the antennas to eliminate any resonances. Possible average powers emitted by systems listed in Table 2 based on the above system characterization are summarized in Table 3.

**Table 3**

<b>GPR <math>f_c</math> (MHz)</b>	<b>Possible Peak Voltage Pulse</b>	<b>Possible Average Power (W) (100 ohm load)</b>	<b>Approximate Emitted Power (mW)</b>	<b>NPRM suggested Average Power (mW)</b>
12.5	8000	640	6400	2.7
25	4000	160	1600	5.4
50	2000	40	400	1.2
100	1000	10	100	5.4
200	500	2.5	25	14
225	444	1.97	20	17
250	400	1.6	16	19
450	222	0.5	5	45
500	200	0.4	4	50
900	111	0.125	1.25	81
1000	100	0.1	1	88
1200	80	0.064	0.64	100
1500	70	0.049	0.49	119
2000	50	0.025	0.25	150

(The numbers in Table 3 are for illustration purposes. In practice, peak voltage and antenna efficiencies at the lower frequencies are substantially lower than what is assumed here. At the higher frequencies, the antenna efficiencies can be slightly higher than assumed. Compensating for the slightly higher the output power that may result is

unnecessary inasmuch as a major portion of the energy is dissipated into the medium under investigation.)

- 4.6 Table 3 clearly indicates the mismatch between proposed rules and what the industry needs. GPRs that operate above about 250 MHz readily fit under the power levels suggested by the FCC NPRM. Under 250 MHz, the proposed power limits are at odds with feasible implementations. Figure 4 below shows the information in graphic form.

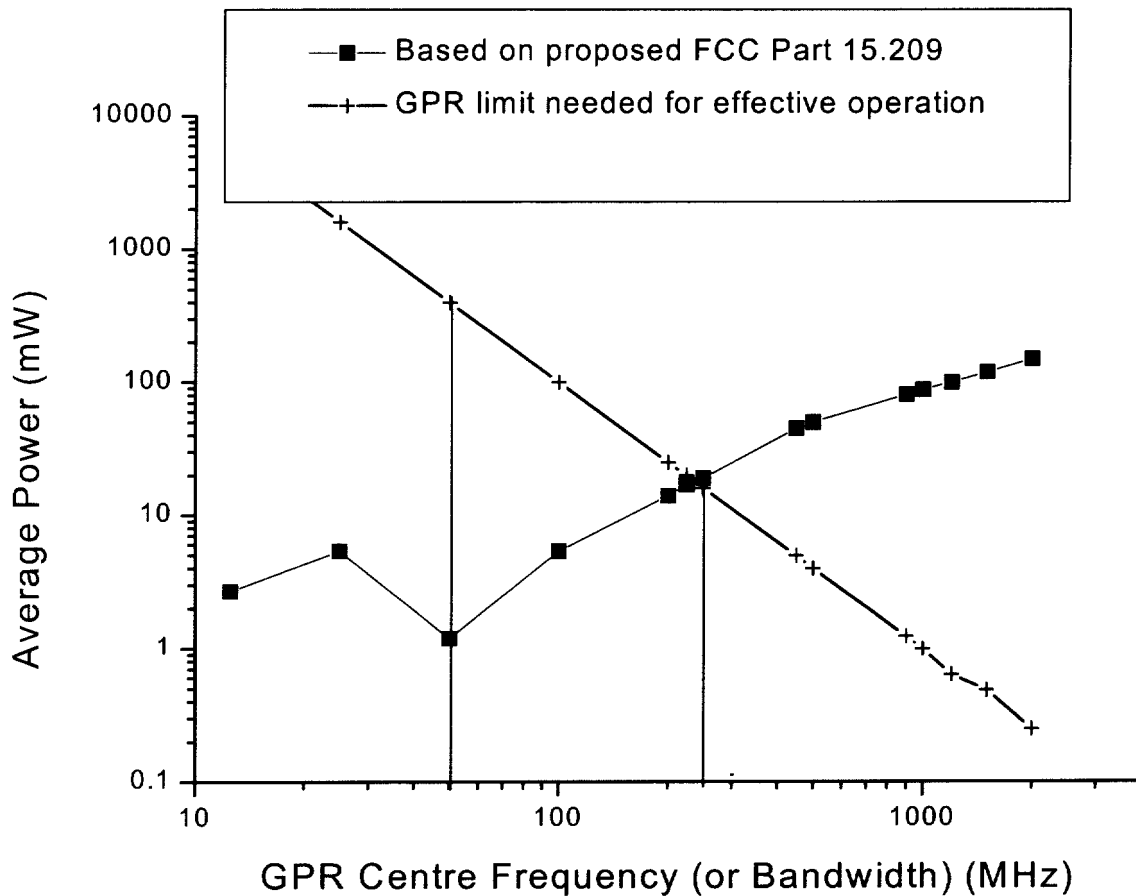


Figure 4 Average power limits for GPR systems based on FCC Part 15.209 and, what is needed for effective operation.

- 4.7 The lower frequency GPRs are often characterized as geological mapping systems. Their primary use is mapping geologic structure to depths of tens of meters below the surface. These systems primarily see use in rural and remote areas when used for mining applications, glacier sounding, major dam and road construction, etc. These are important applications, and the FCC rules must accommodate systems capable of handling them.

## 5. Suggestions for Emission Limits on GPR systems

- 5.1 Emissions limits are most readily expressed in terms of average power emitted, so we recommend adopting this as the standard approach for characterizing UWB GPR systems. This approach to specifying output power has been used in Part 15.213, covering underground pipe and cable locating devices. This is a widespread application for GPR.
- 5.2 For power levels (emitted field levels), we suggest the following limits, which reflect a compromise solution.

Below a defined frequency,  $f_1=50$  MHz, average power should be limited to a maximum of value  $P_1=500$  mW. That power level will allow existing technology to be used. Given that there has never been an interference problem and proliferation of such devices will be highly limited, the power level proposed is realistic and meets current user concerns.

Above  $f_1$ , up to a frequency  $f_2=250$  MHz ( the frequency at which practice and Part 15.209 levels meet in Table 3), the accepted power would drop to the value  $P_2=20$  mW, which is the NPRM proposed level at that frequency.

Above  $f_2$ , the power limit could be kept at  $P_2$  .

The proposed limits are depicted graphically in Figure 5. Although the low-frequency limits are higher than originally proposed, it must be stressed that the vast majority of the power is transferred into soil and rock and poses no interference concern.

Note that the proposed power level is substantially below that proposed in the NPRM at the GPS frequency band, and so offers additional protection to GPS.

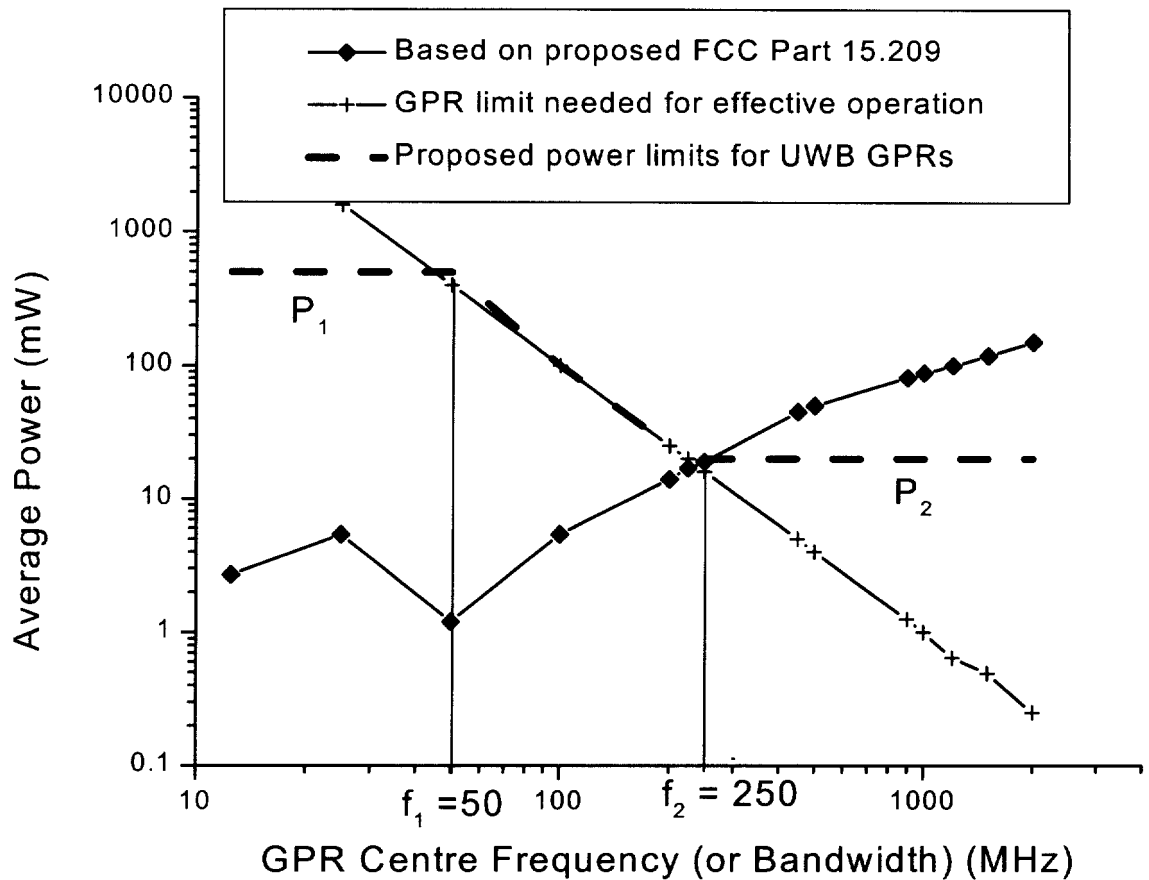


Figure 5 Figure 4 with the addition of proposed power limits for UWB GPR systems

- 5.3 UWB GPRs should be allowed to operate with a peak-to-average ratio independent of bandwidth. We recommend a maximum of 100,000:1 (100 dB), which is typical of current low frequency, deep sounding UWB GPRs. The high ratio results from relatively long intervals between pulses, not high peak power.
- 5.4 GPR units generally have a low utilization duty cycle. The units are frequently quiescent for long periods of time between observations, which in turns further reduces the long-term average power emitted. This is especially true for the low frequency geological GPR systems which must be transported (often by hand) through rough terrain between recordings. The interference risk from these devices is extremely low.

- 5.5 Many GPR applications are in areas where the emitted signal can never reach the outside world. Measurements in underground mines, drill holes, tunnels, and pipes are common and these uses should not be constrained by surface GPR limits. The FCC rules should provide an exception that allows GPRs to operate underground without regard to the technical limits applicable to surface operation.

## **6. Suggestions for Measuring and Characterizing GPR Emission Levels**

- 6.1 The most critical aspect of characterizing GPR systems emissions in general is that of quantifying the amount of power that might leak above ground and act as a potential source of interference. The traditional method of placing the device “in air” on a turntable and making worst case measurements -- followed by a correction to allow for ground absorption -- is quite practical for high frequency GPRs, those with center frequencies above about 250 MHz. These GPR units are physically small and readily managed in the test lab. For such GPR devices, continuing with this practice is an acceptable approach.
- 6.2 Some have suggested that real GPR response could be tested with a cell of “representative” ground material upon which the GPR is placed for testing. This proposal is quite impractical at low frequencies where cells many meters in height, width, and depth would need to be constructed. Furthermore, a “representative material” to put in the cell can have a wide range of values of physical properties (conductivity, permittivity, and permeability). Realistically, this suggestion would be too complex to be cost effectively implemented by the average test house.
- 6.3 The easiest quantity to measure on a large, low-frequency UWB GPR system is the output of the transmitter when connected to a resistive load impedance equivalent to the antenna it normally drives. This is suggested as a realistic approach that might be taken. The output of impulsive UWB GPR’s can be readily measured using existing spectrum analyzers to provide a measure of spectral content directly
- 6.4 In addition, the use of sampling oscilloscopes to examine the transient character of the output would allow examination of the peak and average signals, duty cycles, and rise times (which indicate the highest frequency content available to be transmitted).
- 6.5 A measure of total peak and average power can be readily obtained with these measures. To complete the emissions analysis, it is necessary to characterize the antenna to be employed with the transmitter. At low GPR frequencies (typically less than 100-200 MHz), the bulky size limits practical antennas to electric or magnetic dipoles. A mathematical model for these antennas on a variety of soil conditions could be used to indicate the maximum level of emission that could be transferred into the air for an antenna placed on the ground. A typical fraction of available power (we recommend –40dB) could be used to indicate above ground emissions. A more sophisticated formula might be evolved with extensive modeling.

- 6.6 Our recommendation is to use the procedure described just above for GPRs that operate below 250 MHz, and standard test lab procedures as described in 6.1 for GPRs with center frequencies above 250 MHz. This suggested approach is a pragmatic and cost effective solution.

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